Historical Comparisons of Morbidity and Mortality for Vaccine-Preventable Diseases in the United States

Sandra W. Roush, MT, MPH
Trudy V. Murphy, MD
and the Vaccine-Preventable Disease Table Working Group

Context National vaccine recommendations in the United States target an increasing number of vaccine-preventable diseases for reduction, elimination, or eradication.

Objective To compare morbidity and mortality before and after widespread implementation of national vaccine recommendations for 13 vaccine-preventable diseases for which recommendations were in place prior to 2005.

Design, Setting, and Participants For the United States, prevaccine baselines were assessed based on representative historical data from primary sources and were compared to the most recent morbidity (2006) and mortality (2004) data for diphtheria, pertussis, tetanus, poliomyelitis, measles, mumps, rubella (including congenital rubella syndrome), invasive *Haemophilus influenzae* type b (Hib), acute hepatitis B, hepatitis A, varicella, *Streptococcus pneumoniae*, and smallpox.

Main Outcome Measures Number of cases, deaths, and hospitalizations for 13 vaccine-preventable diseases. Estimates of the percent reductions from baseline to recent were made without adjustment for factors that could affect vaccine-preventable disease morbidity, mortality, or reporting.

Results A greater than 92% decline in cases and a 99% or greater decline in deaths due to diseases prevented by vaccines recommended before 1980 were shown for diphtheria, mumps, pertussis, and tetanus. Endemic transmission of poliovirus and measles and rubella viruses has been eliminated in the United States; smallpox has been eradicated worldwide. Declines were 80% or greater for cases and deaths of most vaccine-preventable diseases targeted since 1980 including hepatitis A, acute hepatitis B, Hib, and varicella. Declines in cases and deaths of invasive *S pneumoniae* were 34% and 25%, respectively.

Conclusions The number of cases of most vaccine-preventable diseases is at an all-time low; hospitalizations and deaths have also shown striking decreases.

JAMA. 2007;298(18):2155-2163 www.jama.com

VACCINES ARE AMONG THE greatest achievements of biomedical science and public health,[1,2] stimulating protective immune responses against acute and chronic infectious diseases, as well as some infectious diseases that result in cancer.[3-5] In the United States, vaccination programs have made a major contribution to the elimination of many vaccine-preventable diseases and significantly reduced the incidence of others. Vaccine-preventable diseases have societal and economic costs in addition to the morbidity and premature deaths resulting from these diseases—the costs include missed time from school and work, physician office visits, and hospitalizations.[6-14] National recommendations provide guidance for use of vaccines to prevent or eliminate 17 vaccine-preventable diseases, namely diphtheria, pertussis, tetanus, poliomyelitis, measles, mumps, rubella (including congenital rubella syndrome), influenza, invasive *Haemophilus influenzae* type b (Hib), hepatitis B, hepatitis A, rotavirus, varicella, herpes zoster (shingles), and disease caused by many of the most important types of *Streptococcus pneumoniae*, *Neisseria meningitidis*, and human papillomavirus (HPV).

This report summarizes the historical and current state of 12 of these diseases for which national recommendations were in place prior to 2005 (diphtheria, pertussis, tetanus, poliomyelitis, measles, mumps, rubella [including congenital rubella syndrome], invasive Hib, acute hepatitis B, hepatitis A, varicella, *S pneumoniae*), in addition to smallpox, for which vaccination has not been routinely recommended since 1971.[15] Influenza is not covered in this study; assessing the effects of influenza vaccine requires a different approach than is used for other vaccine-preventable diseases because the prevalent influenza viruses and vaccine change annually, and yearly vaccination is required for protection.

To provide a context for viewing vaccine-preventable disease morbidity and mortality, we describe elements of the US national immunization program, including development of immunization policy, vaccine distribution and coverage assessment, vaccine safety monitoring, and surveillance.

Development of US Immunization Policy

The US immunization policy is developed by the Advisory Committee on Immunization Practices[16] of the Cen-

Author Affiliations: National Center for Immunization and Respiratory Diseases (NCIRD); Centers for Disease Control and Prevention, Atlanta, Georgia.
The Vaccine-Preventable Disease Table Working Group appears at the end of this article.
Corresponding Author: Sandra W. Roush, MT, MPH; National Center for Immunization and Respiratory Diseases; Centers for Disease Control and Prevention; 1600 Clifton Rd; MS C-25; Atlanta, GA 30333 (sroush@cdc.gov).

ters for Disease Control and Prevention (CDC). The Advisory Committee on Immunization Practices reviews relevant scientific information and develops evidence-based recommendations for the use of licensed vaccines for infants and children, adolescents, and adults. Professional organizations also provide vaccination recommendations, which often are harmonized with the Advisory Committee on Immunization Practices recommendations.[17,18] The Advisory Committee on Immunization Practices has responsibility for establishing the list of vaccines available to infants and children and to adolescents eligible to receive vaccines through the Vaccines for Children Program.[19] Since 1994, the program, established by Section 1928 of the Social Security Act,[19] has allowed children who are uninsured and from low-income families to receive vaccinations as part of routine care, supporting the integration of vaccination and primary care.

Vaccine Distribution and Coverage Assessment

Since the licensure of inactivated poliovirus vaccine in 1955, the national immunization program, in partnership with state, local, and private providers, has taken a primary role in purchasing and distributing vaccines for the public sector.[19] Vaccines through the Vaccines for Children program are available to clinicians at no charge for eligible children and adolescents. The program contributes to achieving high vaccination coverage levels and ensuring that children have access to newly recommended vaccines. There is no equivalent program for adults who are uninsured and of low-income status.

Since 1994, the National Immunization Survey[20-22] has provided national, state, and selected urban area estimates of vaccination coverage rates for US children between the ages of 19 and 35 months, including new vaccines as they are licensed and recommended for use. In 2004, the estimated vaccination coverage for children aged 19 to 35 months exceeded for the first time the Healthy People 2010 goal of 80% or greater for the proportion of children who receive all vaccines that have been recommended for universal administration for at least 5 years.[23] Healthy People 2010 is a compendium of national health objectives designed to serve as a roadmap for improving the health of the people of the United States during the first decade of the 21st century.[24] Since 1989, vaccination requirements have expanded to cover schools and day care settings, ensuring high vaccination coverage among infants and children in these environments.[25-30] New systems are being developed to measure vaccine coverage rates among older children and adults.[31-36] Assessing vaccination coverage identifies groups at risk of vaccine-preventable diseases, focuses efforts to improve uptake, and is a measure of the effectiveness of communicating immunization recommendations.[23,37]

An increasing number of resources, including state-based immunization reg-

Table 1. Historical Comparison of Morbidity and Mortality for Vaccine-Preventable Diseases With Vaccines Licensed or Recommended Before 1980: Diphtheria, Measles, Mumps, Pertussis, Poliomyelitis, Rubella, Smallpox, Tetanus[a]

Vaccine-Preventable Disease	Prevaccine No. (y)				Vaccine Date(s), y[f]	Most Recent Postvaccine Reported No.		Prevaccine Estimated Annual No. vs Most Recent Reported No. (% Reduction)	
	Estimated Annual Average		Peak						
	Cases[b]	Deaths[c]	Cases[d]	Deaths[e]		Cases, 2006[g]	Deaths, 2004[h]	Cases	Deaths
Diphtheria	21 053 (1936-1945)	1822 (1936-1945)	30 508 (1938)	3065 (1936)	1928-1943	0	0	21 053 (100)	1822 (100)
Measles	530 217 (1953-1962)	440 (1953-1962)	763 094 (1958)	552 (1958)	1963, 1967, 1968	55	0	530 162 (99.9)	440 (100)
Mumps	162 344 (1963-1968)	39 (1963-1968)	212 932 (1964)	50 (1964)	1940s, 1967	6584	0	155 760 (95.9)	39 (100)
Pertussis	200 752 (1934-1943)	4034 (1934-1943)	265 269 (1934)	7518 (1934)	1914-1941	15 632	27	185 120 (92.2)	4007 (99.3)
Poliomyelitis, acute	19 794 (1941-1950)	1393 (1941-1950)	42 033 (1949)	2720 (1949)	1955, 1961-1963, 1987	0	0	19 794 (100)	1393 (100)
Poliomyelitis, paralytic	16 316 (1951-1954)	1879 (1951-1954)	21 269 (1952)	3145 (1952)	1955, 1961-1963, 1987	0	0	16 316 (100)	1879 (100)
Rubella	47 745 (1966-1968)	17 (1966-1968)	488 796 (1964)	24 (1968)	1969	11	0	47 734 (99.9)	17 (100)
Congenital rubella syndrome	152 (1966-1969)	Not available	20 000 (1964-1965)	2160 (1964-1965)	1969	1	0	151 (99.3)	Not available
Smallpox	29 005 (1900-1949)	337 (1900-1949)	110 672 (1920)	2510 (1902)	1798	0	0	29 005 (100)	337 (100)
Tetanus	580 (1947-1949)	472 (1947-1949)	601 (1948)	511 (1947)	1933-1949	41	4	539 (92.9)	468 (99.2)

[a] Footnote letters correspond to Box 1.

Box 1. Explanation of Variables for Table 1

Footnote letters correspond to Table 1.

Diphtheria

[b,d]Number of reported cases from 1936-1945[53]
[c,e]Reported number of deaths, 1936-1945[54-56]
[f]Vaccine dates: the Children's Vaccine Initiative[57]
[g]Cases reported to the National Notifiable Diseases Surveillance Systems (NNDSS) for 2006[58]
[h]Deaths reported in 2004[59]

Measles

[b,d]Number of reported cases for 1953-1962[53]
[c]Average reported deaths 1953-1962 is 440.[54,56]
[e]Peak reported deaths 1953-1962 was 552 (in 1958).[54,56]
[f]Vaccine dates: measles vaccines were first licensed March 21, 1963. First vaccines included attenuated Edmonston B vaccine, given with immune globulin and killed measles vaccine. Killed vaccine production ceased in 1967. "Further attenuated" Schwarz strain was licensed in 1965 and produced until 1976. "More attenuated" Moraten strain was licensed in 1968.
[g]Cases reported to NNDSS for 2006. Of the cases reported, 24 were indigenous and 31 were imported.[58]
[h]Deaths reported in 2004[60]

Mumps

[b,d]Number of reported cases, 1963-1968[61]
[c,e]Reported number of deaths, 1963-1968[54]
[f]Vaccine dates: inactivated mumps vaccine was available in the 1940s (no longer available); attenuated (Jeryl Lynn strain) was licensed in 1967.[57]
[g]Cases reported to NNDSS for 2006[58]
[h]Deaths reported in 2004[59]

Pertussis

[b,d]Number of reported cases for 1934-1943[53]
[c]Reported number of deaths, 1934-1943.[54-56] Pertussis deaths declined steadily during the 1920s.[55]
[e]Peak number of deaths reported was 9269 in 1923.[55]
[f]Vaccine dates: the Children's Vaccine Initiative[57]
[g]Cases reported to NNDSS for 2006[58]
[h]Deaths reported to Centers for Disease Control and Prevention (CDC) in 2004[62]

Poliomyelitis

Poliomyelitis cases were reported as "acute" until 1950; 1951-1980 poliomyelitis cases were reported as "total" or "paralytic."
[b,d]Number of reported cases, 1941-1950 and 1951-1954[63]
[c,e]Reported number of deaths, 1941-1950 and 1951-1954[54]
[f]Vaccine dates: inactivated polio vaccine (IPV) was used routinely 1955-early 1960s. Oral polio vaccine (OPV) monovalent type 3 was licensed in 1961, monovalent type 1 and 2 in 1962, and trivalent in 1963.[57] Trivalent OPV used routinely 1963-1999. Enhanced inactivated polio vaccine (eIPV) has been used exclusively since 2000.
[g]Cases reported to NNDSS for 2006[58]
[h]No cases or deaths were reported to CDC in 2004.[60]

Rubella and Congenital Rubella Syndrome (CRS)

[b]For rubella, number of reported cases for 1966-1968[63]; for CRS, number is averaged from retrospective surveys (1966-1969).[64]
[c]For rubella, reported number of deaths, 1966-1968[54]
[d]Peak reported number of rubella cases, associated with the 1964-1965 epidemic[65]; for CRS, number is estimated, associated with the 1964-1965 epidemic.[65]
[e]For rubella, peak reported number of deaths, 1968[54]; for CRS, peak number is estimated, associated with the 1964-1965 epidemic.[65]
[f]Vaccine dates: for rubella and CRS, the Children's Vaccine Initiative[57]
[g]For rubella and CRS, cases reported to NNDSS for 2006[58]
[h]For rubella and CRS, among the cases reported in 2004, no deaths were reported to the CDC.[60]

Smallpox

[b,c,d,e]For all prevaccine numbers, national reports only available during vaccine era and the smallpox endemic period 1900-1949; total number includes both variola major and variola minor.[66]
[f]Vaccine dates: year smallpox vaccination widely known through publication; widespread vaccination use primarily due to establishment of school laws in the 1850s and routine universal vaccination at 1 year of age in the 1920s.
[g]Cases reported to NNDSS for 2006[58]
[h]Last reported case in the United States in 1949; worldwide eradication of smallpox was declared in 1980.[66,67]

Tetanus

[b]Number of reported cases for 1947-1949.[63] Incidence was steadily decreasing even before vaccine became available; data unavailable before 1947.
[c]Reported number of deaths for 1947-1949[54,56]
[d]Peak number of reported cases for 1948[63]
[e]Peak reported number of deaths for 1947[54,56]
[f]Vaccine dates: the Children's Vaccine Initiative[57]
[g]Cases reported to NNDSS for 2006.[58] Between 1999-2004, the 5-year average number of reported tetanus cases was 31.[60,68]
[h]Deaths reported in 2004[59]

istries,[38] have become available to maintain immunization records for infants and children, adolescents, and adults. Immunization registries are confidential, computerized information systems that maintain vaccination data from multiple health care resources. Immunization registries can enhance vaccine coverage by generating reminder and recall notifications. Immunization information systems are registries that have additional capabilities, such as vaccine management, adverse event reporting, and lifespan vaccination histories. Immunization information systems are available for both public and private sector health care clinicians. During 2005, 75% of public vaccination provider sites and 44% of private vaccination provider sites contributed vaccination data to an immunization information system.[38]

Vaccine Safety Monitoring

Ensurance of vaccine safety is a core function related to the national immunization program and is a shared responsibility involving the CDC, the US Food and Drug Administration, other federal agencies, and vaccine resources in the public and private sectors. Reporting through the Vaccine Adverse Events Reporting System and increasing use of postlicensure monitoring is essential to determine whether the safety profiles established in prelicensing studies are reflected during use in the general population, and to detect previously unrecognized or rare adverse events. New scientific approaches are being used to identify rare, serious adverse events that might be associated with a vaccine and may be detectable only after widespread use in the population.[39-42] The National Childhood Vaccine Injury Act of 1986 (Pub L No. 99-660) established the National Vaccine Injury Compensation Program, which provides recourse for individuals who believe they were injured by recommended vaccination.[43]

Surveillance

Assessing the impact of the national immunization program on disease morbidity and mortality requires assessments of both vaccination coverage and the burden of disease.[44] In national disease surveillance, state and local public health officials rely on health care providers, laboratories, and other public health personnel to report notifiable diseases to state and local health departments. In the United States, requirements for reporting diseases and conditions are mandated by state laws or regulations. The list of reportable diseases in each state differs, although there are certain diseases reported in common by all states.[45] The CDC and the Council of State and Territorial Epidemiologists have established guidelines for state health departments' reporting cases of selected diseases to CDC's National Notifiable Diseases Surveillance System.[44-46] To improve the specificity and enhance the comparability of state-reported cases of vaccine-preventable diseases, case definitions for surveillance have been developed.[47] Enhanced surveillance systems have also been designed to provide public health data for monitoring disease patterns and the effectiveness of the national immunization program.[48-51] Characterizing the impact of vaccines on chronic disease (eg, hepatitis B and liver cancer, HPV and cervical cancer)[3-5] requires surveillance designed to capture changes over extended periods of time.

Deaths attributed to vaccine-preventable diseases are another indicator of the impact of vaccination programs. Deaths are reported to the National Notifiable Diseases Surveillance System. In addition, the National Center for Health Statistics, National Vital Statistics System, provides data used to monitor the number of deaths,[52] including deaths due to vaccine-preventable diseases. National Notifiable Diseases Surveillance System death reports, with the vital statistics data based on registration of birth and death events at the state and local level, allow monitoring of the impact of vaccination on the most serious outcomes of vaccine-preventable diseases.

METHODS

We established prevaccine estimated annual averages and determined the number of (reported or estimated) cases, deaths, and hospitalizations (when available) for vaccine-preventable diseases. The prevaccine information was from a wide variety of historical reporting sources. We sought to identify the most comprehensive and credible of these sources. The historical average number of cases and deaths per year were taken from the number reported or estimated for a representative time period before vaccine licensure, or before widespread implementation of the vaccine-specific immunization program. To give a wider context for the historical baseline (annual average), we also determined the peak numbers of cases and deaths, and indicated the period covered. The vaccine dates on the tables are either the date of license (approved for use) in the United States or the date of routine use (year the vaccine was recommended for routine use for any or all of the target age groups).

The most current available reported or estimated numbers of cases (mostly 2006), deaths (2004-2006), and hospitalizations (2006) were determined using sources most representative of the burden of disease. Reported cases and deaths (TABLE 1 and BOX 1) were used for those diseases for which the national passive surveillance system served as the primary resource. Current estimates (rather than reports) were used for diseases for which active surveillance or modeling provided the most representative indication of disease impact (TABLE 2 and BOX 2).

The percent reduction in the number of cases, deaths, and hospitalizations for each of the vaccine-preventable diseases was calculated as the difference between the baseline and the current numbers. The disease-specific numbers refer to the entire population unless a specific age group is indicated, although

Table 2. Historical Comparison of Morbidity, Mortality, and Hospitalizations for Vaccine-Preventable Diseases With Vaccines Licensed or Recommended Between 1980 and 2005: Hepatitis A, Acute Hepatitis B, *Haemophilus influenzae* Type b, Pneumococcal Disease, Varicella[a]

Vaccine-Preventable Disease	Prevaccine No. (y)					Vaccine Date(s), y[g]	Most Recent Postvaccine No., 2006				Prevaccine Estimated Annual No. vs Most Recent Estimated No. (% Reduction)		
	Estimated Annual Average			Estimated Peak									
	Cases[b]	Hospitalizations[c]	Deaths[d]	Cases[e]	Deaths[f]		Reported Cases[h]	Estimated Cases[i]	Estimated Hospitalizations[j]	Deaths[k]	Cases	Hospitalizations	Deaths
Hepatitis A	117 333 (1986-1995)	6863 (1986-1995)	137 (1986-1995)	254 518 (1971)	298 (1971)	1995	3579	15 298	895	18	102 035 (87.0)	5968 (87.0)	119 (86.9)
Acute hepatitis B	66 232 (1982-1991)	7348 (1982-1991)	237 (1982-1991)	74 361 (1985)	267 (1985)	1981, 1986	4713	13 169	1461	47	53 063 (80.1)	5887 (80.1)	190 (80.2)
Invasive *Haemophilus influenzae* type b	20 000 (1980s)	Not available	1000 (1980s)	Not available	Not available	1985, 1987, 1990	208 (29 type b; 179 type unknown)	< 50 (2005)	Not available	<5 (2005)	19 950 (≥ 99.8)	Not available	995 (≥ 99.5)
Invasive pneumococcal disease	63 067 (1997-1999)	Not available	6500 (1997-1999)	64 400 (1999)	7300 (1999)	2000	5169	41 550 (2005)	Not available	4850 (2005)	21 517 (34.1)	Not available	1650 (25.4)
Varicella	4 085 120 (1990-1994)	10 632 (1988-1995)	105 (1990-1994)	5 358 595 (1988)	138 (1973)	1995	48 445	612 768	1276	19 (2004)	3 472 352 (85.0)	9356 (88.0)	86 (81.9)

[a] Footnote letters correspond to Box 2.

Box 2. Explanation of Variables for Table 2

Footnote letters correspond to Table 2.

Hepatitis A

[b]Cases: estimated acute clinical (symptomatic) cases 1986-1995. Average symptomatic cases were reported to the National Notifiable Diseases Surveillance Systems (NNDSS) for 1986-1995[68] multiplied by the multiplier for underreporting (approximately 4.3).[69]

[c]Hospitalizations: average reported cases 1986-1995[68] multiplied by proportion hospitalized from NNDSS (25%)

[d]Deaths: average reported cases 1986-1995[68] multiplied by proportion of deaths from NNDSS (0.5%)

[e]Estimated acute clinical cases 1971. Reported cases for 1971 (59 606)[53] multiplied by multiplier for underreporting (approximately 4.3)[69]

[f]Deaths per year: reported cases 1971 (59 606)[53] multiplied by proportion of deaths from NNDSS (0.5%)

[g]Hepatitis A vaccine was licensed during 1995-1996.[94]

[h]Cases reported to NNDSS for 2006[58]

[i]Estimated acute clinical cases 2006. Reported cases (NNDSS)[58] were multiplied by multiplier for underreporting (approximately 4.3).[69]

[j]Hospitalizations: reported cases 2006[58] were multiplied by proportion hospitalized from NNDSS (25%).

[k]Number of deaths shown is estimated; reported cases 2006[58] were multiplied by proportion of deaths from NNDSS (0.5%).

Acute Hepatitis B

[b]Cases: estimated acute clinical (symptomatic) cases 1982-1991. Average symptomatic cases reported to the NNDSS for 1982-1991[68] were multiplied by the multiplier for underreporting (approximately 2.8).[70]

[c]Hospitalizations: average reported cases 1982-1991[68] were multiplied by proportion hospitalized from NNDSS (31%).

[d]Deaths: average reported cases 1982-1991[68] were multiplied by proportion of deaths from NNDSS (1%).

[e]Estimated acute clinical cases for 1985. Reported cases (26 654)[68] were multiplied by multiplier for underreporting (approximately 2.8).[70]

[f]Peak deaths per year: reported cases 1985 (26 654)[68] were multiplied by proportion of deaths from NNDSS (1%).

[g]Plasma-derived hepatitis B vaccine was licensed in 1981; recombinant hepatitis B vaccine was licensed in 1986.

[h]Cases reported to NNDSS for 2006[58]

[i]Estimated acute clinical cases reported to NNDSS for 2006[58] were multiplied by multiplier for underreporting (approximately 2.8).[70]

[j]Hospitalizations: reported cases 2006[58] were multiplied by proportion hospitalized from NNDSS (31%).

[k]Number of deaths shown is estimated; reported cases 2006[58] were multiplied by proportion of deaths from NNDSS (1%).

Invasive *Haemophilus influenzae* type b (Hib)

[b,d]Estimated, applied to cases less than 5 years old[71]

[g]1985 polysaccharide vaccine was introduced for children aged 2-5 years; 1987 polysaccharide protein conjugate vaccine was available for children aged 18 months to 5 years; 1990 polysaccharide protein conjugate was introduced for the primary series starting at 2 months.

[h]Isolates of unknown serotype are included as type b for national reporting. Of the 208 cases of invasive Hib reported to the NNDSS in 2006 for children younger than 5 years, 29 were serotype b and 179 had unknown serotype.[58]

[i]Estimate based on observed number of cases in the Active Bacterial Core Surveillance (ABCs) surveillance area (total population 35 147 052).[72] Race- and age-specific rates of Hib were applied from the aggregate surveillance areas[72] to the race- and age-specific distribution of the 2005 US population.[73]

[k]Number of deaths due to invasive Hib among children younger than 5 years was estimated for 2005; estimate based on the ABCs surveillance area.[72]

Invasive Pneumococcal Disease

[b]Estimated mean annual number of cases nationally 1997-1999; ABCs Report, Emerging Infections Program Network, *Streptococcus pneumoniae*.[74] For children younger than 5 years, this number was estimated as 16 069, calculated from unadjusted extrapolation of *S pneumoniae* annual rates for children less than 5 years old. The US population younger than 5 years was estimated as 19 175 798 in the US 2000 Census.[73]

[d]Estimated mean annual number of deaths nationally 1997-1999; ABCs Report. [74]

[e,f]ABCs Report.[74] For children younger than 5 years, the peak number of cases during this time was in 1998, with an estimated 16 798 cases. This estimate was calculated from unadjusted extrapolation of *S pneumoniae* annual rates of children less than 5 years old; the US population younger than aged 5 years was 19 175 798 in the 2000 US Census.[73]

[g]The 7-valent pneumococcal polysaccharide protein conjugate vaccine was approved in 2000 for use in infants and young children. The 14-valent pneumococcal polysaccharide was approved in 1977 and the 23-valent pneumococcal polysaccharide was approved in 1983.

[h]Cases reported to NNDSS for 2006.[58] There were 1861 cases reported as *S pneumoniae* invasive disease in those less than 5 years old.

[i,k]Number shown is estimated; ABCs Report.[75]

Varicella

[b]Annual number of cases estimated from the National Health Interview Survey[76] using a general question concerning any medical conditions during the 2 weeks before the interview. The 2-week case counts were adjusted to represent annual case counts and averaged over the 5-year period.

[c]Annual number of hospitalizations shown in the table for the prevaccine era was estimated using the National Hospital Discharge Survey.[77] Using the Nationwide Inpatient Sample, Davis et al provided alternative estimates of 13 746 hospitalizations per year during 1993-1996, and 3729 per year during 2001, or a decrease of 64.9%.[95]

[d,f]Varicella mortality.[79] Varicella is very rare among elderly individuals. An unknown but large proportion of deaths attributed to varicella among individuals aged 50 years and older are likely to be herpes zoster or causes other than varicella. Disregarding data for individuals aged 50 years and older, there were 84 deaths annually attributed to varicella during 1990-1994 in individuals aged 0 to 49 years.

[e]Peak number of varicella cases was estimated from the product of an estimated incidence rate of 21.8 cases per 1000[76] and a total residential population of 245 807 100.[80]

[g]Varicella vaccine was licensed in March 1995.[81]

[h]Cases reported to NNDSS for 2006.[58] In 2005, 31 states reported 32 242 cases to NNDSS, but in 2006, 33 states reported 48 445 cases.

[i]After the varicella vaccine program was implemented, the NNDSS passive surveillance system and the Varicella Active Surveillance System (VASP) demonstrated an approximately 85% decline in the incidence of varicella. Percent decline is the average decline in VASP in the 4 states (Michigan, West Virginia, Texas, Illinois) that have consistently reported varicella data through NNDSS. Applying (1-0.85) to the annual number of cases in 1990-1994 yields an estimated 612 768 cases in the postvaccine era. NNDSS data compare 2006 data to 1993-1995 data.[58,60,68,82] VASP data cover 1995-2005.

[j]Estimated reduction in hospitalizations represents MEDSTAT percent reduction applied to National Hospital Discharge Survey data for annual number of hospitalizations.[83] From the prevaccination period to 2002, hospitalizations in the MEDSTAT data set due to varicella declined by 88%.

[k]Deaths reported in 2004.[59] Varicella is very rare among elderly individuals. An unknown but large proportion of deaths attributed to varicella in individuals aged 50 years and older are likely to be herpes zoster or causes other than varicella.[84] Disregarding data (2004) for individuals aged 50 years and older, there were 8 deaths in 2004 attributed to varicella, for a decline of 90.5%.

some vaccines may have targeted specific age or risk groups.

The data included here were collected for routine public health surveillance purposes, did not include linkages to personal identifiers, and thus were considered research not requiring institutional review for human subjects protections.

RESULTS

The prevaccine era number of cases and deaths and the most recent number (reported or estimated) of cases and deaths for 13 vaccine-preventable diseases are summarized in Table 1 and Box 1 and Table 2 and Box 2. The number of hospitalizations is shown for diseases and years with available information (Table 2 and Box 2).

Table 1 provides the historical comparison of 8 diseases for which a vaccine was licensed or recommended prior to 1980, including diphtheria,[53-59] measles,[53,54,56,58,60] mumps,[54,57-59,61] pertussis,[53-58,62] poliomyelitis,[54,57,58,60,63] rubella and congenital rubella syndrome,[54,57,58,60,63-65] smallpox,[58,66,67] and tetanus.[54,56-60,63,68] Our comparison of the period before national vaccination recommendations vs the 2006 number of reported cases shows greater than 99% declines in the number of cases for diphtheria (100%), measles (99.9%), paralytic poliomyelitis (100%), rubella (99.9%), congenital rubella syndrome (99.3%), and smallpox (100%) (Table 1 and Box 1). Smallpox has been eradicated worldwide,[66] and endemic transmission of poliovirus,[85-87] measles virus,[78,88-93] and rubella[8] virus has been eliminated in the United States. There were no reported deaths due to diphtheria, measles, mumps, paralytic poliomyelitis, or rubella; deaths due to congenital rubella syndrome are not reported. The decline in cases of mumps was 95.9%, of tetanus 92.9%, and of pertussis 92.2%. The decline in tetanus deaths was 99.2% and in pertussis deaths 99.3%.

Table 2 provides the historical comparison of the number of cases, deaths, and hospitalizations for diseases for which a vaccine was licensed or recommended after 1980 but before 2005 (including hepatitis A,[53,58,68,69,94] acute hepatitis B,[58,68,70] invasive Hib,[58,71-73] invasive pneumococcal disease,[58,73-75] and varicella).[58-60,68,76,77,79-84,95] Our comparison of the period before national vaccination recommendations vs the most recent estimated number of cases and deaths shows declines in the estimated number of cases ranging from 34.1% to 99.8% or greater, and declines in the number of deaths ranging from 25.4% to 99.5% or greater. Cases of invasive Hib disease declined 99.8% or greater and deaths declined 99.5% or greater. Reduction in cases was 87.0% and in deaths 86.9% for hepatitis A; 80.1% in cases and 80.2% in deaths for acute hepatitis B; 34.1% in cases and 25.4% in deaths for invasive pneumococcal disease; and 85.0% in cases and 81.9% in deaths for varicella. Hospitalizations declined by 87.0% for hepatitis A, 80.1% for acute hepatitis B, and 88.0% for varicella.

COMMENT

The number of cases of most vaccine-preventable diseases is at an all-time low; hospitalizations and deaths from vaccine-preventable diseases have also shown striking decreases. These achievements are largely due to reaching and maintaining high vaccine coverage levels from infancy throughout childhood by successful implementation of the infant and childhood immunization program.[1] It has been estimated that vaccination with 7 of the 12 routinely recommended childhood vaccines prevents an estimated 33 000 deaths and 14 million cases of disease in every birth cohort, saves $10 billion in direct costs in each birth cohort, and saves society an additional $33 billion in costs that include disability and lost productivity.[14]

There are important limitations to consider when reviewing the decrease in vaccine-preventable diseases over time. The number of cases and deaths reported to surveillance systems and the number of cases and deaths presented in the tables are likely to underestimate the number of cases and deaths throughout the reporting periods.[96] Reporting and disease estimates from surveillance systems are affected by changes in disease awareness, tests and testing protocols, case definitions, reporting jurisdictions, and reporting practices over time.[44,46,47,63,64] During the span of the national immunization program, changes have occurred in the population (eg, growth, racial/ethnic distribution, age structure), health care (eg, advances in treatment, vaccine formulations available), socioeconomic determinants (eg, education level, standard of living), vaccine practice (eg, early use of vaccines before national recommendations are made, vaccine coverage levels, inclusion of new groups in national recommendations), and other health predictors (eg, access to health care). Neither the historical nor current data are adjusted for these nonvaccine factors[48,97]; epidemiologic and economic analyses to further characterize vaccine impact will need to take into account the specific factors that have affected the burden of each disease over time.

The long-term health and economic benefits of vaccines are not included here, resulting in an underestimate of the true impact of vaccination programs. Current surveillance systems are not designed to measure the burden of chronic disease. No attempt was made to compile the rare but serious adverse events that have been causally associated with some vaccines or to weigh the risks and benefits of vaccination, which has been done elsewhere.[98-104]

The footnotes in Box 1 and Box 2 provide specific references for the historical and methodological details used to determine the prevaccine and most current disease numbers presented. Some of the recent data rely on estimates or statistical modeling to account for infections that are asymptomatic but infectious; these models are referenced in Table 1 and Box 1 and Table 2 and Box 2. Because the methodology for presenting historical and current numbers is specific to each disease, comparisons should not be made between diseases.

Added health benefits could be achieved by increasing vaccine uptake of currently recommended vaccines among adolescents and adults. An increasing number of vaccines that reduce the morbidity and mortality of disease in adolescents (eg, meningococcal; HPV; and new pertussis, tetanus, and diphtheria vaccines) create opportunities and challenges.[18] Providing routine access to all vaccines recommended for adolescents will require different approaches for adolescents than for infants and children.[105] Ensuring routine access to pertussis, influenza, pneumococcal, and zoster vaccines can reduce vaccine-preventable disease morbidity and mortality among adults,[106-108] and may decrease disease transmission to other vulnerable populations.[107,109] Achieving high vaccination uptake among adults will require a greater understanding of the benefits of vaccination by clinicians and patients, and adoption of vaccination provision as a part of adult preventive health care.[110,111] Racial/ethnic disparities were not identified in the 2005 National Immunization Survey for vaccines that have been recommended for universal administration to children aged 19 to 35 months for at least 5 years.[112] However, substantial racial/ethnic differences in adult vaccination uptake have been documented in national surveys,[113] even among adults most likely to be vaccinated (eg, individuals with the highest education level and individuals who undergo frequent health care visits).[114] The greatest additional gains are likely to come from achieving higher vaccination coverage among adolescents and adults.

Vaccine-preventable diseases still exist, with 1 exception (smallpox). History demonstrates that because vaccine-preventable diseases find susceptible individuals in populations, importation of disease into undervaccinated populations poses risks for outbreaks.[93,115] Lapses in vaccination result in the disease again becoming common in populations, accompanied by its morbidity and mortality.[116-119] Strengthening surveillance for vaccine-preventable diseases better informs appropriate public health action.[8,37,46,89,120,121] Historical evidence suggests that there is a predictable inverse relationship between the levels of vaccine-preventable diseases and safety concerns, with safety concerns likely to emerge as first-hand experience with vaccine-preventable diseases decreases.[122] The links between perception of benefits, perception of risks, and the decision to vaccinate emphasize the importance of ensuring the safety of vaccines and clearly communicating their risks and benefits, especially when disease rates are low.

Vaccines are one of the greatest achievements of biomedical science and public health.[1] Continued efforts to improve the efficacy and safety of vaccines and vaccine coverage among all age groups will provide overall public health benefit. The challenges in vaccine development, vaccine financing, surveillance, assessment, and vaccine delivery are opportunities for the future.[123-125]

The Vaccine-Preventable Disease Table Working Group: Michelle M. Basket, BS; John K. Iskander, MD, MPH; John S. Moran, MD, MPH; Jane F. Seward, MBBS, MPH; Annemarie Wasley, ScD (Centers for Disease Control and Prevention, Atlanta, Georgia).

Author Contributions: Ms Roush had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Roush, Murphy, Basket.
Acquisition of data: Roush, Murphy, Moran, Seward, Wasley.
Analysis and interpretation of data: Roush, Murphy, Iskander, Moran, Seward, Wasley.
Drafting of the manuscript: Roush, Murphy, Basket.
Critical revision of the manuscript for important intellectual content: Roush, Murphy, Iskander, Moran, Seward, Wasley.
Statistical analysis: Roush, Murphy, Seward, Wasley.
Administrative, technical, or material support: Roush, Murphy, Basket, Iskander, Moran.
Study supervision: Roush, Murphy.
Funding/Support: The authors were employees of the US federal government (Centers for Disease Control and Prevention [CDC]) when this work was conducted and prepared for publication. No funding/support was received from other sources.
Role of the Sponsor: The CDC was responsible for the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, and approval of the manuscript.
Financial Disclosures: None reported.
Additional Contributions: We thank the following individuals who collaborated to define disease- and vaccine-specific historical context and data presentation: Gregory L. Armstrong, MD, and Francisco Averhoff, MD, MPH (National Center for Preparedness, Detection, and Control of Infectious Diseases; CDC); Beth P. Bell, MD, MPH, Stephen L. Cochi, MD, MPH, Amanda Cohn, MD, Margaret M. Cortese, MD, Kimberly Cushing, MPH, Gustavo H. Dayan, MD, Lyn Finelli, DrPH, MS, Sonja S. Hutchins, MD, MPH, DrPH, Katrina Kretsinger, MD, MA, Gina T. Mootrey, DO, MPH, Tamara Pilishvilli, MPH, Susan B. Redd, Susan E. Reef, MD, Abigail Shefer, MD, Tami Hilger Skoff, MS, Pamela U. Srivastava, MS, and Tejpratap Tiwari, MD (National Center for Immunization and Respiratory Diseases; CDC); and Mark Papania, MD, MPH (Immunization Safety Office; CDC). No compensation was received by these individuals for their contributions to this article.

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